Reentry Survivability Analysis of the Wide-Field Infrared Explorer (WIRE)

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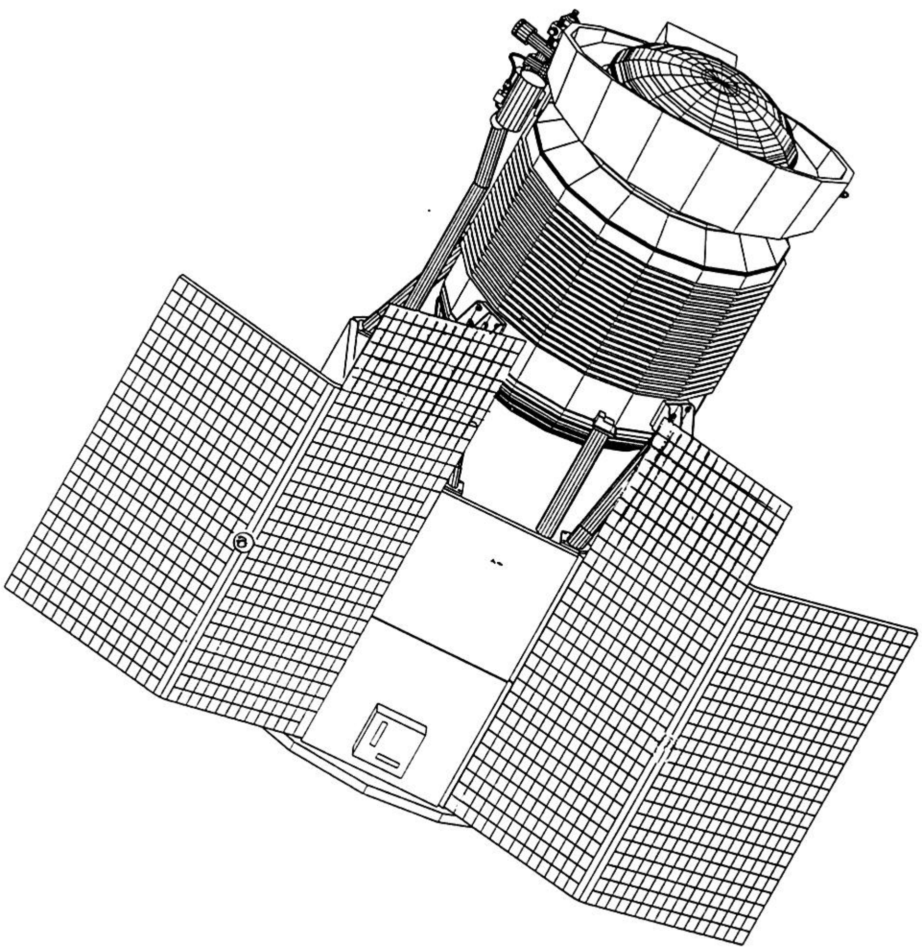

Wide-Field Infrared Explorer (WIRE) satellite

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EXECUTIVE SUMMARY

A reentry survivability analysis of components of the Wide-Field Infrared Explorer (WIRE) spacecraft was performed to assess the risk of significant debris resulting from an uncontrolled reentry. WIRE does not have a propulsion system so a controlled reentry is impossible. Flight dynamics analysis shows that WIRE's orbit is decaying and the nominal prediction is for re-entry into Earth's atmosphere by May 2003. This survivability analysis was performed in accordance with NASA Policy Directive, NPD 8710.3, "NASA Policy For Limiting Orbital Debris Generation" and NASA Safety Standard, NSS 1740.14, "Guidelines and Assessment Procedures for Limiting Orbital Debris". This analysis utilized Debris Analysis Software (DAS) Release 1.0, supplied through NASA's Orbital Debris Program Office at the Johnson Space Center (JSC). JSC is the NASA Lead Center for orbital debris research. This document describes the analysis method used for the breakup of WIRE, the assumptions and manipulations employed to model various resultant fragments and provides an estimate of the reentry debris casualty area from those components predicted to survive reentry. A total of 38 objects were modeled, with 9 predicted to survive creating a total debris casualty area of 5.75 square meters. This is within the NSS 1740.14 Guideline number 7 upper limit of 8 square meters and represents a risk of 1 in 19300 for causing a casualty within the ground track for WIRE which has a 97.5 degree orbital inclination.

1. INTRODUCTION

The NASA Goddard Space Flight Center (GSFC) Wide-Field Infrared Explorer (WIRE) spacecraft was launched on March 5, 1999, into a 540 kilometer (km) low earth orbit inclined at 97.5 degrees to the equator, aboard a Pegasus rocket [reference 1]. Figure 1 [reference 2], shows a model of the WIRE spacecraft in orbital configuration with the major components identified. Additional figures in Sections 2 and 3 provide expanded views of the structure showing the relationship between the major components. The WIRE instrument is a cryogenically-cooled 30cm Cassegrain infrared imaging telescope. The planned WIRE science mission ended shortly after launch due to the cover coming off before the spacecraft was under full attitude control. This precipitated a series of events that caused the spacecraft to boil off its cryogen and spin out of control. The solid hydrogen supply was depleted within a day and no useful data was returned. After the cryogen was exhausted, Goddard was able to gain control of the satellite and use it as a test bed.

At launch, the WIRE spacecraft had a mass of 248 kilograms (kg) [reference 3] and external dimensions minus the solar panels of approximately 1.3 meters (m) in diameter by 1.9 m long [reference 2]. There is no propulsion unit and the three-axis attitude control is by reaction wheels and magnetic torquer rods, not thrusters, thus there is no propellant. Tanks are present, however, for the storage of cryogenics used by the instrument. These tanks were depleted following the launch and the current mass of WIRE is approximately 238 kg. There are no other pressurized vessels or propellant tanks.

The basic methodology for this analysis follows the guidelines in NASA Safety Standard, NSS 1740.14, "Guidelines and Assessment Procedures for Limiting Orbital Debris", in particular Guideline number 7, "Survival of Debris from the Post Mission Disposal Atmospheric Reentry Option". For this analysis, the intact WIRE spacecraft was assumed to break up at an altitude of 78 km, which has been determined to be the approximate altitude at which most spacecraft structures begin to disintegrate [references 4]. Below this altitude, various components and subcomponents were assumed to become free falling and were modeled individually. A detailed description of the modeling approach can be found in Section 2, Methods of Analysis.

The calculation of the demise altitudes and debris casualty area for the various items modeled was performed using NASA Orbital Debris Analysis Software (DAS) Version 1.0, developed by the Orbital Debris Program Office at the Johnson Space Center [reference 5]. DAS is an acceptable analysis tool per the NASA Safety Standard. More sophisticated, higher fidelity tools such as the ORSAT software are available to the JSC debris analysis group. Close correlation between the DAS results for EUVE and ORSAT calculations for similar objects on the Compton Gamma Ray Observatory (CGRO) [reference 6], provides confidence in the DAS results. Analyses for EUVE using both DAS and ORSAT showed DAS to be the most conservative approach yielding a debris area about twice that predicted by the ORSAT application.

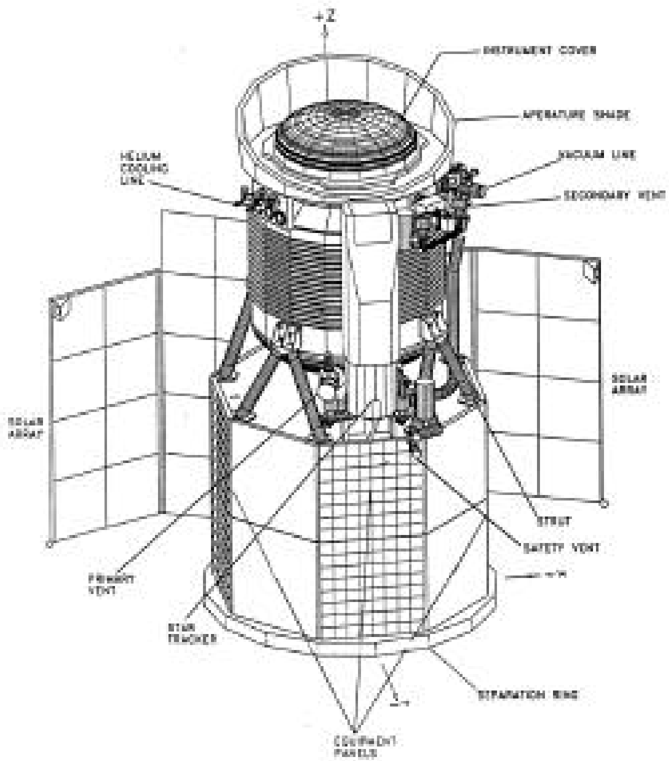

Figure 1. The WIRE Spacecraft in its Orbital Configuration [reference 6]

2. METHOD OF ANALYSIS

2.1 NASA REQUIREMENTS

2.1.1 NPD 8710.3, "NASA POLICY FOR LIMITING ORBITAL DEBRIS GENERATION"

NPD 8710.3 states that it is NASA policy to, "Conduct a formal assessment in accordance with NSS 1740.14, on each NASA program/project" [reference 7].

2.1.2 NSS 1740.14, "GUIDELINES AND ASSESSMENT PROCEDURES FOR LIMITING ORBITAL DEBRIS"

Section 7 of NSS 1740.14 contains the following Guideline:

> 7-1 *Limit the risk of human casualty:* If a space structure is to be disposed of by uncontrolled reentry into the earth's atmosphere, the total debris casualty area for components and structural fragments surviving reentry will not exceed 8 m^2. The total debris casualty area is a function of the number and size of components surviving reentry and of the average size of a standing individual.

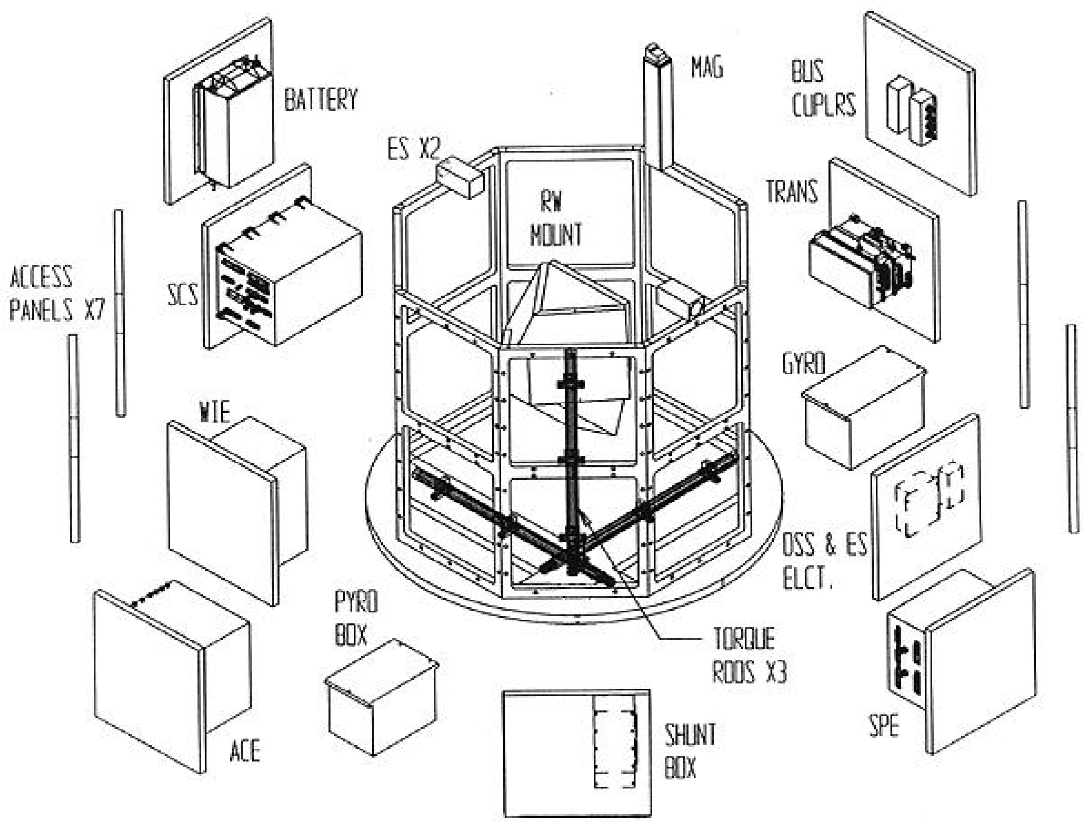

Figure 2. An exploded view of the WIRE primary structure showing its major components

In the Method to Assess Compliance with the Guidelines for Section 7, it is stated,

> 3. If the parent body is larger than 0.5 m in any dimension and consists of multiple components, it will break up into components of significant size during reentry. Each of these components must then be evaluated separately. The design of the structure must be reviewed and all components that are larger than 0.25 m in any dimension must be identified.

The Method description goes on to state that all objects identified as exceeding the dimensional requirement of 0.25 m must be modeled for reentry debris.

2.2 NASA ORBITAL DEBRIS ANALYSIS SOFTWARE (DAS) VERSION 1.0

DAS is a DOS based program that is configured to follow the structure of NSS 1740.14. In particular it is divided into options that correspond to the Guidelines sections in the NSS. This analysis was performed using the Guideline 7 option for uncontrolled reentry debris.

Figure 2 shows an exploded view of the complete WIRE spacecraft, which should be helpful in understanding references to spacecraft components in the next sections.

DAS allows the modeling of objects as spheres, cylinders, boxes or plates only. This means that actual spacecraft fragments, which are rarely uniform in shape, require manipulation to be modeled as the closest equivalent to one of these shape options. Also, the NSS encourages the modeling of objects as either spheres or cylinders because these shapes are modeled most accurately by the software, so this was done for WIRE components whenever practical. In addition, DAS cannot directly model the wall thickness of hollow objects. Manipulation of material properties can be used to compensate for this limitation, in accordance with a procedure recommended by the experts at JSC. The results of these various compensations and manipulations are shown in Table 1 but the underlying philosophies and methods are described in detail in the following sections.

2.2.1 MODELING OF OBJECTS – *SHAPE*

As stated in 2.2 it was necessary to perform various manipulations of the dimensions of actual objects in order to convert them to a close equivalent in one of the shapes allowed by DAS. The following paragraphs describe examples of these manipulations and the rationale behind them.

2.2.1.1 Tubes and Rings

The Pegasus Adapter Ring (PAR) is a large diameter (~ .45 m) aluminum annulus or ring with a proportionately very thin rim (~ 0.05 m square cross-section). In order to model this object in DAS, manipulation was required. It was decided to model the PAR as a cylinder using the actual height (thickness) of the ring, and the known mass (from the mass properties table) but with a modified diameter. The diameter of the cylinder was calculated to have the same total surface area on that face as the annulus. This ensured that the drag experienced while descending with the circular face foremost would be essentially correct, although the drag on the other axis would be reduced slightly. The Bipod Struts are tubular and were modeled in a similar way. This is considered a conservative approach because the slight reduction in drag in one axis tends to increase the likelihood the object will survive reentry. In section 7 of the NSS it is stated:

"A necessary and sufficient condition for a structure to survive reentry is

$$H < M \times h_a / A_s$$"

Where

H = the heat load per unit area experienced by a reentering space structure (J/m^2)
M = the component mass (kg)
h_a = the specific heat of ablation of the nominal material (J/kg)
A_s = the surface area of the component (m^2)

Therefore, the probability of surviving reentry is inversely proportional to surface area.

2.2.1.2 Boxes

Although boxes can be modeled directly in DAS, for this analysis they were usually converted to equivalent cylinders. The thickness (height) and cross-sectional area of the box were maintained at their nominal values but the length and width of the box were converted to the diameter necessary to generate the required cross-sectional area. As an example, the WIRE Attitude Control Electronics (ACE) box, which is .254 m square by 0.203 m thick, was modeled as a cylinder .256 m in diameter and 0.254 m long. A diameter was calculated that provides the same area as the .254 x .203 face (0.052 m^2).

2.2.1.3 Complex Structures

Various major components of WIRE are highly irregular in shape or do not lend themselves easily to conversion to cylinders or spheres; examples are various composite structures that are hollow, L-shaped or U-shaped in cross-section. The WIRE equipment panels are comprised of a composite web sandwiched between composite skins. Each of the complex shapes had to be manipulated individually using a variety of techniques, including material density modification (see 2.2.2). The modification techniques sought to preserve key features of the objects such as surface area along the major axis. In many instances, manipulation had to be based on best engineering judgment.

2.2.2 MODELING OF OBJECTS – *MATERIAL PROPERTIES*

DAS contains a materials database of the key parameters for most of the materials commonly used in spacecraft construction. These material properties produce accurate results when used for solid objects but as mentioned previously, DAS cannot model the wall thickness of hollow objects such as boxes, so a simple modification of material properties is necessary to produce satisfactory results. The basic approach is to create a "synthetic" material that has a modified density, specific heat and heat of fusion but other parameters identical to the parent material. The synthetic material density is simply the known or estimated mass of the object divided by its modeled volume. For example, the ACE box which has an aluminum outer shell, has a mass of

10.77 kg [reference 3] and a volume of 0.13 m^3 giving a synthetic material density of 822 kg/m^3, compared to the actual density of aluminum of 2700 kg / m^3. The corresponding values for specific heat and heat of fusion are found by multiplying their nominal values by the ratio of the actual to synthetic densities, 822/2700 or 0.30 in this example. A similar approach was used to calculate "synthetic" materials properties for the Instrument and all of the boxes housed within the main bus structure. Material properties for all the materials used in this study are shown in Table 1.

The effectiveness of this compensation method was demonstrated in the Reentry Survivability Analysis of the Extreme Ultraviolet Explorer (EUVE) Satellite [reference 8]. In the analysis, an MPS box on EUVE was very similar in dimensions and mass to an MPS box on CGRO. The demise altitude for the CGRO MPS box calculated using the ORSAT software configured for the wall thickness of the box, was 71.7 km [reference 6]. The demise altitude for the EUVE box calculated by inputting similar initial conditions into DAS and using synthetic material compensation was 71.5 km.

2.2.3 MODELING OF OBJECTS – *MASS*

The Mass Properties Tables for WIRE [reference 3] contains the masses of all major components, many sub-components and even small parts such as the torque rods. However, the masses of some of the items modeled for this analysis had to be calculated or estimated.

2.3 ASSUMPTIONS

2.3.1 INITIAL CONDITIONS

The WIRE spacecraft was assumed to begin to break up at an altitude of 78 km, the default value for DAS and as previously mentioned the accepted value for the typical initial breakup altitude for reentering objects. The reentry trajectory is preprogrammed into DAS.

2.3.2 BREAKUP SEQUENCE

The order in which the structure was modeled to break-up was somewhat arbitrary. Every attempt was made to follow a logical progression but it is simply not possible to predict if two objects would separate as somewhat intact objects or if the process would cause more massive disintegration. In other cases, parts of one structure also formed parts of another.

2.3.3 OBJECT SELECTION

The WIRE spacecraft consists of several major structural components and numerous smaller items. The majority of the structural housings such as the instrument cryostat and electronics boxes are constructed of aluminum alloy. The support structures to which these components are mounted are primarily made of graphite/epoxy composite materials. Using experience gained from a previous analysis [reference 8] in which some examples of large aluminum components showed that they have a small probability of survival, only the largest or heaviest aluminum objects were generally selected for analysis.

Table 1: Materials Database used for Reentry Calculations

Material Name	Material Density (kg/m^3)	Specific Heat Capacity (J/kg-K)	Thermal Conductivity (W/m-K)	Heat of Fusion (J/kg)	Heat of Oxidation (J/kg-O2)	Melt Temp (K)	Synthetic Material Based on
Al 6061-T6	2700.0	896.0	167.0	386116.0	34910934.0	859.0	-
Copper	8938.0	430.7	395.9	205932.0	9832002.0	1356.0	-
Gr/Ep	1550.5	879.3	4.9	23.0	12305703.0	700.0	-
Steel AISI 304L	8000.0	500.0	16.0	286098.0	16816980.0	1698.0	-
Titanium	4437.0	805.2	7.2	393559.0	32480264.0	1943.0	-
INST	254.0	84.3	167.0	36329.0	34910934.0	859.0	Al 6061-T6
SA	133.0	44.2	167.0	19029.0	34910934.0	859.0	Al 6061-T6
WIE	675.0	224.1	167.0	96590.0	34910934.0	859.0	Al 6061-T6
PAR	334.0	110.7	167.0	47709.0	34910934.0	859.0	Al 6061-T6
STRUCT	42.0	23.6	4.9	1.0	12305703.0	700.0	Gr/Ep
UF	730.0	132.5	7.0	64761.0	32480264.0	1943.0	Titanium
BAT	2200.0	137.5	16.0	78673.0	16816980.0	1698.0	Steel AISI 304L
SPE	733.0	243.1	167.0	104780.0	34910934.0	859.0	Al 6061-T6
SHUNT	978.0	324.6	167.0	139878.0	34910934.0	859.0	Al 6061-T6
ACE	822.0	272.7	167.0	117498.0	34910934.0	859.0	Al 6061-T6
TROD	3953.0	190.5	396.0	91085.0	9832002.0	1809.0	Iron
MAGN	177.0	100.5	4.9	3.0	12305703.0	700.0	Gr/Ep
GYRO	555.0	184.3	167.0	79431.0	34910934.0	859.0	Al 6061-T6
STAR	1721.0	571.2	167.0	246160.0	34910934.0	859.0	Al 6061-T6
SCS	707.0	234.5	167.0	101050.0	34910934.0	859.0	Al 6061-T6
TRANS	721.0	239.1	167.0	103038.0	34910934.0	859.0	Al 6061-T6
SV01	2454.0	153.4	16.0	87755.0	16816980.0	1698.0	Steel AISI 304L
SV02	2432.0	152.0	16.0	86963.0	16816980.0	1698.0	Steel AISI 304L
SV03	2431.0	151.9	16.0	86945.0	16816980.0	1698.0	Steel AISI 304L
SV04	1281.0	80.1	16.0	45827.0	16816980.0	1698.0	Steel AISI 304L
SV05	2475.0	154.7	16.0	88497.0	16816980.0	1698.0	Steel AISI 304L
BUSPANELS	1550.5	7.9	4.9	0.0	12305703.0	700.0	Gr/Ep

Note. Material properties were generated from values in the DAS database, augmented from reference 9. Materials for this table were identified from references 10-25.

The other class of objects selected was those consisting of dense materials with high melting points, which in WIRE were titanium, iron and stainless steel. This report provides results for all objects that are known to meet or exceed the 0.25 m limit, which are also known to be or suspected to be made of these materials.

2.3.4 SMALL OBJECTS

The analysis of WIRE revealed a large number of items that did not meet the 0.25 m minimum length requirement but nonetheless may have a significant probability of reentry. Modeling of examples of these objects, made of titanium, revealed that many of them are likely to survive re-entry. The 4 large titanium fittings used to attach the Bipod to the Instrument are shown to survive. In addition to these larger fittings, there are numerous smaller titanium pieces in the main bus structure. As the NSS does not require analysis of these small objects, no results for them are provided in this report.

3. RESULTS

A comprehensive description and illustrations of the break-up sequences assumed for this analysis are found in the following paragraphs. The input conditions and results for each DAS run are shown in Table 2, which also shows if an object is predicted to survive and if not, the calculated demise altitude.

3.1 RUN 1 – INITIAL BREAK-UP

The initial breakup at 78 km is assumed to consist of separation into the largest cohesive component parts. These are (see Figures 1 and 2):

- The Instrument (INST) Cryostat
- The Safety Vent (SV) System
- The Solar Array (SA) Panels
- The Main Bus Structure (BUSPANEL)
- The Pegasus Adapter Ring (PAR)
- The Bipod Struts (STRUT)
- The Bipod Upper Fittings (UF)
- The Star Tracker (STAR)
- The Magnetometer (MAGN)

The modeled components all demised between 77.96 km and 62.12 km (STAR). The only objects surviving to the ground from this initial break-up were the titanium Bipod Upper Fittings and a portion of the stainless steel Safety Vent System. A total debris area of 2.76 m^2 was generated from these items.

The BUSPANEL was modeled as a cylinder made with synthetic materials based on the known exterior surface materials and the masses for each panel. The first DAS run generated a demise altitude for the BUSPANEL that was then used as the break-up altitude for runs to analyze the behavior of its respective sub-components.

Table 2: DAS Runs for WIRE Components

DAS Run Number	System/Object	Object Identification	Nominal Surfac Material	Object Type	Diameter (m)	Length (m)	Mass (kg)	Synthetic Material	Survive? Yes/No	Demise Alt. (km)
1	WIRE Spacecraft	SPACECRAFT	Al 6061-T6	Cylinder	1.330	1.870	238.21	N/A	No	77.96
1	Instrument Cryostat	INST	Al 6061-T6	Cylinder	0.671	0.805	70.40	INST	No	75.42
1	Solar Array	SA01	Al 6061-T6	Flat Plate	0.876	1.053	6.24	SA	No	77.96
1	Solar Array	SA02	Al 6061-T6	Flat Plate	0.876	1.053	6.24	SA	No	77.96
1	Pegasus Adapter Ring	PAR	Al 6061-T6	Cylinder	0.452	0.050	2.68	PAR	No	77.39
1	Bipod Strut	STRUT01	Gr/Ep	Cylinder	0.019	0.294	0.13	N/A	No	77.40
1	Bipod Strut	STRUT02	Gr/Ep	Cylinder	0.019	0.294	0.13	N/A	No	77.40
1	Bipod Strut	STRUT03	Gr/Ep	Cylinder	0.019	0.294	0.13	N/A	No	77.40
1	Bipod Strut	STRUT04	Gr/Ep	Cylinder	0.019	0.294	0.13	N/A	No	77.40
1	Bipod Strut	STRUT05	Gr/Ep	Cylinder	0.019	0.294	0.13	N/A	No	77.40
1	Bipod Strut	STRUT06	Gr/Ep	Cylinder	0.019	0.294	0.13	N/A	No	77.40
1	Bipod Strut	STRUT07	Gr/Ep	Cylinder	0.019	0.294	0.13	N/A	No	77.40
1	Bipod Strut	STRUT08	Gr/Ep	Cylinder	0.019	0.294	0.13	N/A	No	77.40
1	Bipod Upper Fitting	UF01	Titanium	Cylinder	0.085	0.119	0.50	UF	**Yes**	**0.00**
1	Bipod Upper Fitting	UF02	Titanium	Cylinder	0.085	0.119	0.50	UF	**Yes**	**0.00**
1	Bipod Upper Fitting	UF03	Titanium	Cylinder	0.085	0.119	0.50	UF	**Yes**	**0.00**
1	Bipod Upper Fitting	UF04	Titanium	Cylinder	0.085	0.119	0.50	UF	**Yes**	**0.00**
1	Magnetometer	MAGN	Gr/Ep	Cylinder	0.033	0.330	0.05	MAGN	No	77.96
1	Star Tracker	STAR	Al 6061-T6	Cylinder	0.178	0.203	8.68	STAR	No	62.12
1	Equipment/Access Panels	BUSPANEL	Gr/Ep	Cylinder	1.000	0.787	8.63	BUSPANEL	No	77.96
2	WIRE Instrument Electronics	WIE	Al 6061-T6	Cylinder	0.220	0.279	7.17	WIE	No	65.29
2	Primary Structure	STRUCT	Gr/Ep	Cylinder	1.003	0.787	18.25	STRUCT	No	77.90
2	Battery	BAT	Steel AISI 304	Cylinder	0.160	0.264	11.68	BAT	**Yes**	**0.00**
2	SPE	SPE	Al 6061-T6	Cylinder	0.225	0.275	8.01	SPE	No	63.67
2	Shunt Driver Box	SHUNT	Al 6061-T6	Cylinder	0.093	0.231	1.54	SHUNT	No	66.52
2	Attitude Control Electronics	ACE	Al 6061-T6	Cylinder	0.256	0.254	10.77	ACE	No	59.36
2	Torque Rod	TROD01	Iron	Cylinder	0.028	0.638	1.54	TROD	**Yes**	**0.00**
2	Torque Rod	TROD02	Iron	Cylinder	0.028	0.638	1.54	TROD	**Yes**	**0.00**
2	Torque Rod	TROD03	Iron	Cylinder	0.028	0.638	1.54	TROD	**Yes**	**0.00**
2	Gyro	GYRO	Al 6061-T6	Cylinder	0.202	0.277	4.95	GYRO	No	68.73
2	Spacecraft Computer System	SCS	Al 6061-T6	Cylinder	0.218	0.299	7.88	SCS	No	64.08
2	Transponder	TRANS	Al 6061-T6	Cylinder	0.168	0.242	3.86	TRANS	No	66.48
1	Cryostat Safety Vent	SV01	Steel AISI 304	Cylinder	0.019	0.327	0.23	SV01	No	73.78
1	Cryostat Safety Vent	SV02	Steel AISI 304	Cylinder	0.019	0.287	0.20	SV02	No	73.78
1	Cryostat Safety Vent	SV03	Steel AISI 304	Cylinder	0.019	0.388	0.27	SV03	No	73.60
1	Cryostat Safety Vent	SV04	Steel AISI 304	Cylinder	0.038	0.637	0.93	SV04	**Yes**	**0.00**
1	Cryostat Safety Vent	SV05	Steel AISI 304	Cylinder	0.019	0.254	0.18	SV05	No	73.78

Notes
1. N/A for a synthetic material shows the object is solid and was modeled using its nominal surface material.
2. Masses are from reference 3 or estimated from material and dimensional data.
3. Dimensions are from references 10-25.

3.2 RUN 2 – THE MAIN BUS STRUCTURE

As shown in Figure 3, the WIRE bus structure consists of a complex composite structure to support the various electronics boxes, reaction wheels and torque rods. The structure also contains equipment support panels and access panels, which are all light weight composite structures. The initial break-up altitude for Run 2 is 77.94 km, the BUSPANEL demise altitude from Run 1. All items in Run 2 demised between 77.94 km and 59.36 km except for the battery and torque rods that survived and generated a total debris area of 3.00 m^2.

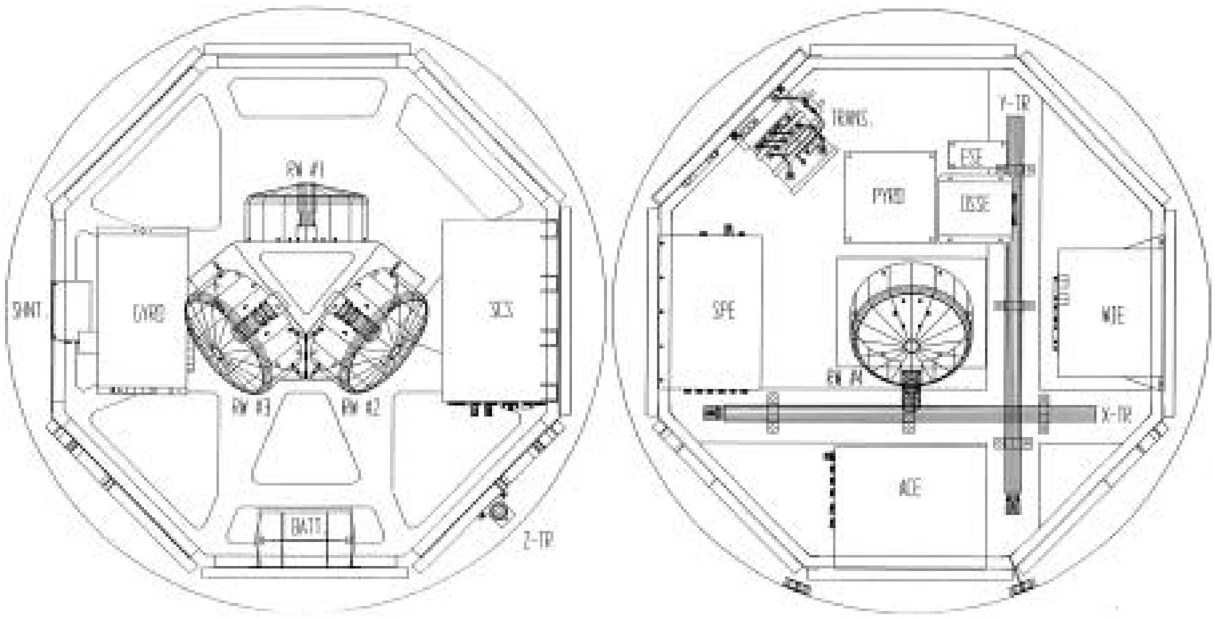

Figure 3. The WIRE Primary Structure (Upper and Lower Sections)

3.3 TOTAL REENTRY DEBRIS CASUALTY AREA FOR WIRE

The **total reentry debris casualty area** calculated for WIRE in accordance with NASA Policy Directive NPD 8710.3, is **5.75 m^2**. Table 3 provides a summary for all objects predicted to survive. Figure 4 provides a pictorial summary of the complete break-up model for WIRE, showing the objects that demise and those that survive.

Table 3. Summary of WIRE Components Predicted to Survive Reentry

Run#	Description of Surviving Object	Principal Constituent Material	Debris Casualty Area for Object (m^2)	Number of Examples of the Object	Total Mass of Objects (kg)	Total Debris Casualty Area (m^2)
1	Bipod Upper Fitting	Titanium	0.49	4	2.00	1.96
1	Cryostat Safety Vent	Stainless Steel	0.79	1	0.93	0.79
2	Torque Rods	Iron	0.78	3	4.62	2.34
2	Battery	Stainless Steel	0.66	1	11.68	0.66
Total						**5.75**

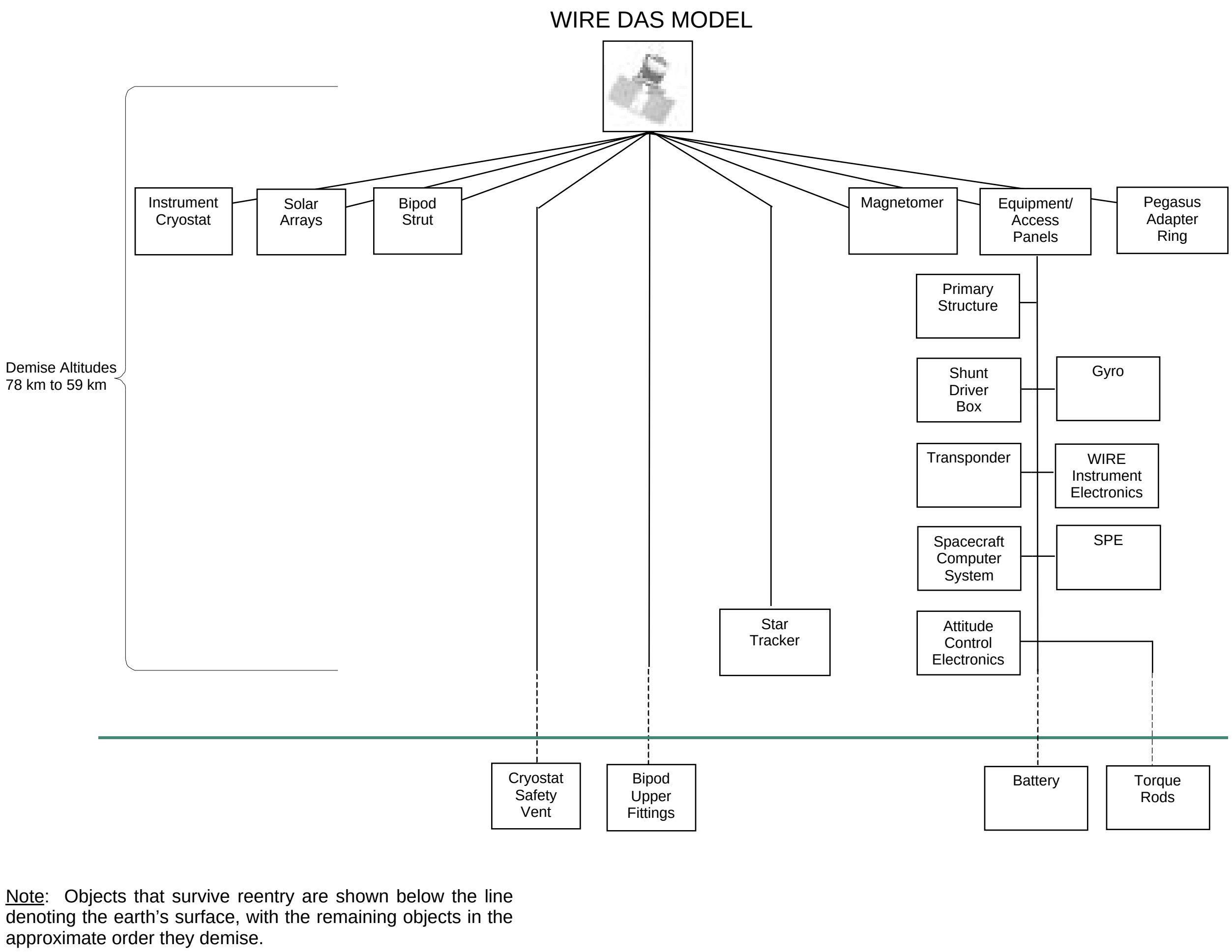

Figure 4. A pictorial summary of the break-up of WIRE.

4. DISCUSSION OF METHODOLOGY

Throughout this analysis situations were encountered where it was necessary to make an assumption, or choose between options. The most common situation involved the shape to use for modeling an irregular object. Based on investigations conducted during the reentry analysis of EUVE [reference 8], objects were transformed into cylinders whenever possible. These investigations found that the best correlation to similar objects modeled for the CGRO reentry analysis was achieved using cylinders. This transformation often involved severe distortion of the object. The other common situation involved the estimation of mass.

Wherever possible, the mass used for analyzing an object was taken from the mass properties data but if this information was not available it was necessary to estimate the mass. This could be difficult given the extensive machining and complex 3-dimensional nature of many of the objects.

In the section describing the various DAS runs, the scenario used for the break-up of the WIRE spacecraft is described in detail. Every one of these runs involved choices and assumptions regarding which part broke away from which, when and in what manner.

Any of these assumptions or choices has the potential to significantly impact the analysis results. There can be a trickle down impact. A change in the demise altitude of a major component could in turn affect the demise altitude of one of its sub-components and so on, possibly resulting in the survival of a component that would demise under a different scenario. Likewise, assumptions about the order in which the structure disintegrates and choices made in modeling multi-part objects affect the results.

In general, a conservative approach was taken when making assumptions or selecting options. Masses and areas were generally overestimated. In the end, the results seem reasonable. All of the aluminum objects demised during reentry. The surviving objects were made of titanium, iron and stainless steel. These materials all have high melting points and other properties that make them likely to survive.

5. CONCLUSIONS

This report has presented a reentry debris analysis for the Wide-Field Infrared Explorer (WIRE) spacecraft performed using Debris Analysis Software (DAS) in accordance with NASA Policy Directive NPD 8710.3, NASA Policy for Limiting Orbital Debris Generation, and NASA Safety Standard NSS 1740.14, “Guidelines and Assessment Procedures for Limiting Orbital Debris”. From this analysis it is estimated that the WIRE spacecraft will generate a maximum debris casualty area of 5.75 m^2 from the survival of 9 individual objects if allowed to reenter without interference. This is within the 8 square meter limit specified in NASA Safety Standard NSS 1740.14, “Guidelines and Assessment Procedures for Limiting Orbital Debris”. The 5.75 m^2 debris casualty area represents a risk of approximately 1 in 19,300 (0.005%) for causing a human casualty within WIRE’s ground track using population density estimates for 1999.

ACRONYMS AND ABBREVIATIONS

ACE	Attitude Control Electronics
CGRO	Compton Gamma Ray Observatory
DAS	Debris Analysis Software
EUVE	Extreme Ultraviolet Explorer
GSFC	Goddard Space Flight Center
JSC	Johnson Space Center
MPS	Modular Power Subsystem
NPD	NASA Policy Directive
NSS	NASA Safety Standard
ORSAT	Object Reentry Survival Analysis Tool
PAR	Pegasus Adapter Ring
RW	Reaction Wheel
SCS	Spacecraft Computer System
SPE	Spacecraft Power Electronics
WIE	WIRE Instrument Electronics
WIRE	Wide-Field Infrared Explorer

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